Electrical-Field Activated Sintering and Forming of Micro-Components

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Dedication

The author wished to dedicate the thesis to his wife Ilyana Janis and families.

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Abstract

As the demand for miniature products has increased significantly, so also has the need for these products to be produced in a rapid, flexible and cost efficient manner. The application of electroplasticity shows significant potential to produce the components by using powder materials. Nevertheless, previous research has shown that there are still significant challenges to be met in order to achieve increased relative densification of product samples and simplification of the processes. The process concept in this study comprises the combination of electrical-field activated sintering and forming processes. Therefore, the aims of the research were to develop the process concept for the manufacture of micro-components and to design the die sets along with other tooling for machine setup to enable the forming of micro-components from powder materials. A comprehensive literature review on micro-manufacturing, size effects, powder metallurgy and the electroplasticity process has been conducted. The development of the die sets for the process has been described, followed by a series of experiments. The FE thermal-electrical analysis was also carried out to study the heating flows of the die sets development during the process. In this research, titanium (Ti) and titanium tin alloy (90Ti10Sn) have been selected for the main powder materials tested for both vacuum and open-air process environment by using a Gleeble® 3800 testing system and Projection Welding machine respectively. Meanwhile, for the additional experiment, copper (Cu) has been selected to be tested in the open-air process environment by using a Projection Welding machine with die sets prepared by the Micro-FAST project. Based on the data collected, this efficient process has the potential to produce components with a high relative density of around 98%. Changes of the particles concerning deformation and breaking are crucial in the course of achieving the densification which differs from a conventional sintering process.

Published Research Papers and Posters

a) Research Papers:

1. **Muhammad Bin Zulkipli**, Yi Qin, Kunlan Huang, Hasan Hazma Hijji, Yihui Zhao and Jie Zhao (6th to 9th August 2015), *"Forming of titanium and titanium alloy miniature-cylinder by electrical- field activated powder sintering and forming"*. 4th International Conference on New Forming Technology (ICNFT2015) – Glasgow, Scotland, United Kingdom. (http://dx.doi.org/10.1051/matecconf/20152110006).

2. Jie Zhao, Yi Qin, Kunlan Huang, **Muhammad Bin Zulkipli** and Hasan Hazma Hijji (6th to 9th August 2015), *"Forming of micro-components by electrical-field activated sintering"*. 4th International Conference on New Forming Technology (ICNFT2015) – Glasgow, Scotland, United Kingdom. (http://dx.doi.org/10.1051/matecconf/20152110001).

3. Kunlan Huang, Yi Qin, Jie Zhao, **Muhammad Bin Zulkipli** and Hasan Hazma Hijji (6th to 9th August 2015), "*Fabrication of NiTi shape memory alloy by Micro-FAST*". 4th International Conference on New Forming Technology (ICNFT2015) – Glasgow, Scotland, United Kingdom. (http://dx.doi.org/10.1051/matecconf/20152110003).

4. Hasan Hijji, Yi Qin, Kunlan Huang, **Muhammad Bin Zulkipli,** Song Yang and Jie Zhao (6th to 8th September 2016), *"Forming Alumina (Al_2O_3) by Micro-FAST"*. 14th International Conference on Manufacturing Research (ICMR2016) – Loughborough, England, United Kingdom. (http://ebooks.iospress.nl/volumearticle/44320).

5. Hasan Hijji, Yi Qin, Kunlan Huang, Song Yang, **Muhammad Bin Zulkipli** and Jie Zhao (6th to 8th September 2016), *"Fabrication of micro components with MSZ material using electrical-field activated powder sintering technology"*. 14th International Conference on Manufacturing Research (ICMR2016) – Loughborough, England, United Kingdom. (http://ebooks.iospress.nl/volumearticle/44319).

b) Research Posters:

1. **Muhammad Bin Zulkipli** & Yi Qin (27th June 2013) *"Development of a New Process for the Forming of Micro-Components"*. Poster presentation. Faculty Engineering Research Presentation Day (RPD 2013) – University of Strathclyde Glasgow, Scotland, United Kingdom. **(2nd Prize for Best Poster Presentation).**

2. **Muhammad Bin Zulkipli** & Yi Qin (20th and 25th June 2014) *"Development of a New Process for the Forming of Micro-Components"*. Poster presentation. Department Design, Manufacture & Engineering Management Poster Critique 2014 and Faculty Engineering Research Presentation Day (RPD 2014) – University of Strathclyde Glasgow, Scotland, United Kingdom.

3. Hasan Hazma Hijji, **Muhammad Bin Zulkipli** & Yi Qin (31st January 2014), *"Development of a New Process for the Manufacture of Micro Parts by Using a Combination of Micro Forming and Fast Technology"*. Poster presentation. 8th Saudi Student Conference – Imperial College London, United Kingdom.

4. **Muhammad Bin Zulkipli** & Yi Qin (17th and 24th June 2015) *"Development of a New Process for the Forming of Micro-Components"*. Poster presentation. Department Design, Manufacture & Engineering Management Poster Critique 2015 – University of Strathclyde Glasgow, Scotland, United Kingdom.

5. **Muhammad Bin Zulkipli** & Yi Qin (31th March 2016) *"Electrical-Field Activated Forming and Sintering of Micro-Components with Titanium and Titanium Alloy"*. Poster presentation. Department Design, Manufacture & Engineering Management Poster Critique 2016 – University of Strathclyde Glasgow, Scotland, United Kingdom.

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Chapter 1: Introduction

1.1. Research Background

In general demands for micro-electromechanical systems (MEMS) and micro-products have significantly increased due to the fast growth that can be seen in the field of biomedicine, telecommunications and automotive engineering. For example, the global industry association Semiconductor Equipment and Materials International (SEMI) has released the sales forecast for semiconductor equipment which had a market value of $37 billion in 2015 to approximately $38 billion in 2016 and enjoys an active growth in the global market of 1.4% [1]. Besides typical MEMS manufacturing methods, significant efforts have been made recently either to scale down traditional processes or to develop the new ones for the manufacture of micro- and nano-products [2]–[5]. For instance, the production of micro-gears which are significant actuating and transmission components used widely in MEMS and micro-mechanical-systems (MMS), is often enabled through ultra-precision machining or lithographic techniques especially LIGA processes [6], [7]. Micro-forming also plays important roles for manufacturers of millions of micro screws through upsetting and rolling every year [8]–[10]. In addition to that, micro-extrusion has been well investigated where it is capable of extruding copper pins in the laboratory with a shaft diameter of 0.5 to 0.8 mm and a wall thickness of 50 to 125 μm [11], [12]. Therefore, based on the previous research and experiment results there is no doubt that micro-products with high precision and accuracy can be produced, nevertheless concerning cycle time and cost for high production, there are still improvements to be made.

In micro-forming, the limits of the process are influenced largely by the workpiece's dimension. This phenomenon is being commonly referred as the size effects. The size effects that exist in metallic materials can be described as grain and feature/specimen size effects. According to Armstrong [13], grain size effect can be represented by the Hall-Petch law which states that the material strengthens as the grain size decreases. Meanwhile for feature/specimen size effects observed when the miniaturisation of the part occurs resulting in the decline of the flow stress. In this feature/specimen size effect, the workpiece cannot be considered as an isotropic continuum due to the huge share of the volume occupied by individual grains with different orientations if the microstructure, surface topology and tools of the workpiece used in the process remain unchanged [12], [14]. It was found that by

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